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(54) **SYSTEM AND METHOD FOR CONTROLLING ENGINE TORQUE TO PREVENT DRIVELINE BUMP WHEN A DRIVER DEPRESSES AN ACCELERATOR PEDAL**

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F02D 28/00 (2006.01)
F02D 9/10 (2006.01)
F02D 41/10 (2006.01)

(52) **U.S. Cl.**

CPC ***F02D 9/10*** (2013.01); ***F02D 41/107*** (2013.01); *F02D 2250/21* (2013.01); *F02D 2250/26* (2013.01)

(58) **Field of Classification Search**

CPC F02D 17/02; F02D 41/042; F02D 41/123; F02N 11/0855; B60W 2500/04; Y02T 10/48

USPC .... 701/102, 107, 110, 112, 114; 123/179.3, 179.4, 349–352, 361, 395, 123/399, 339.1, 339.15, 339.19, 198 D, 123/559.1, 559.3

See application file for complete search history.

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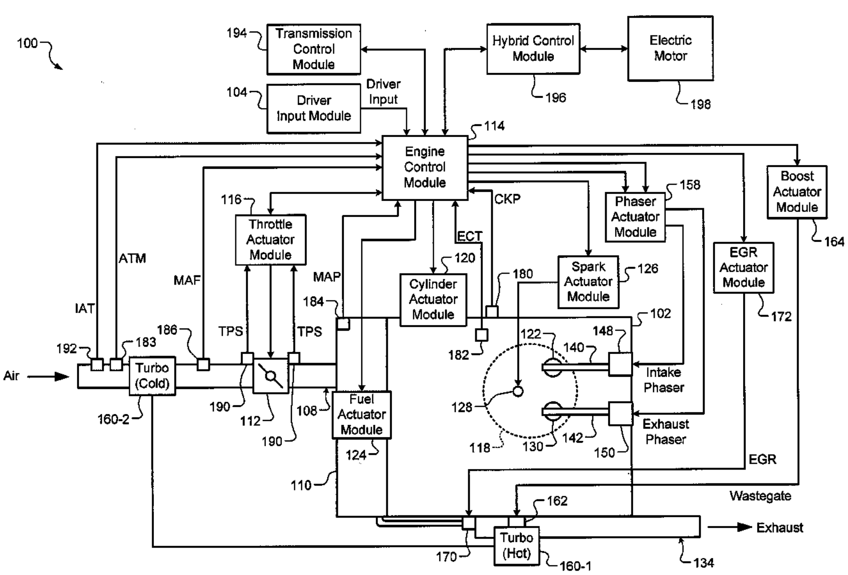
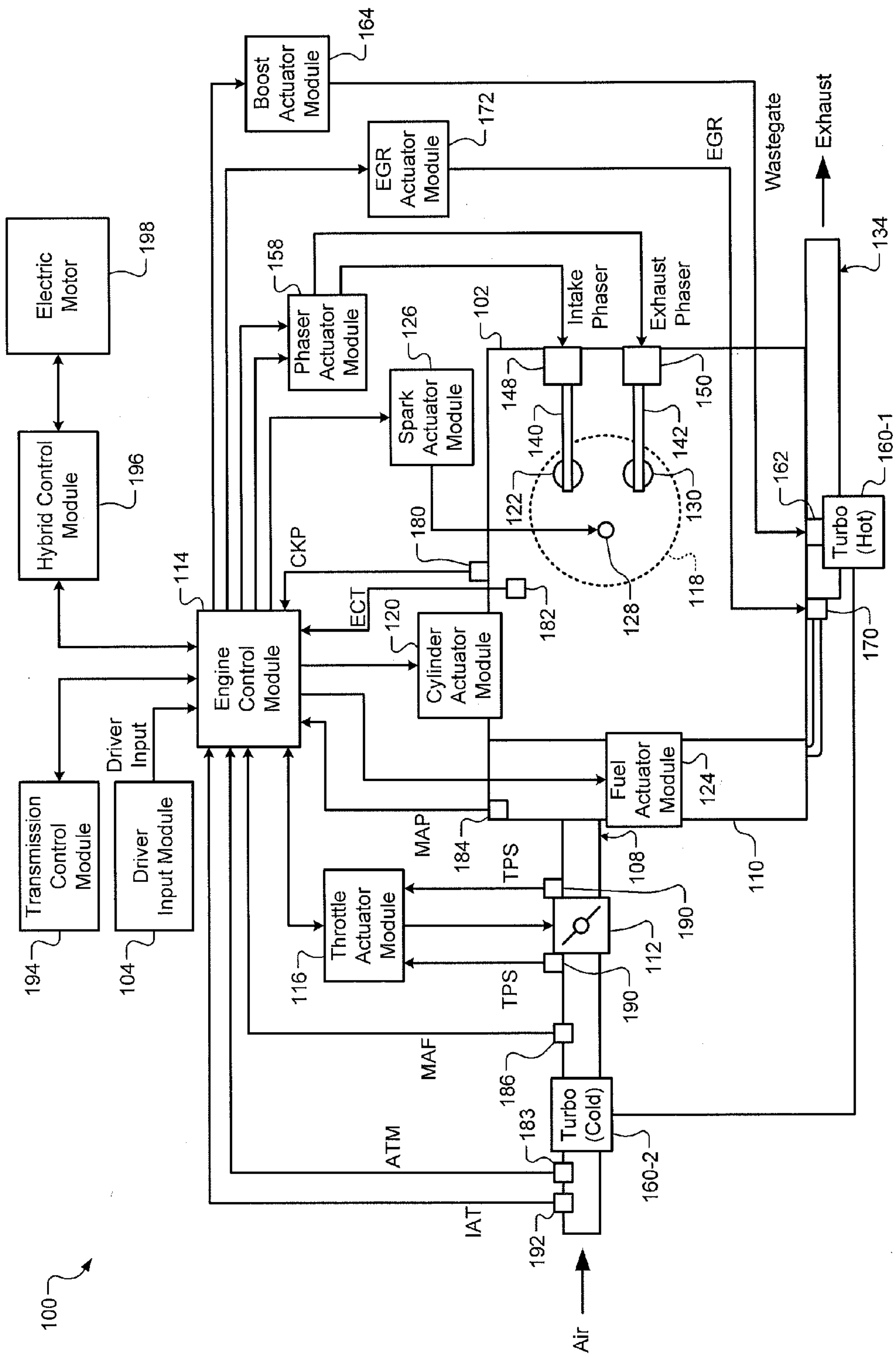
Assistant Examiner — Johnny H Hoang

(57) **ABSTRACT**

A system according the principles of the present disclosure includes a torque determination module and a torque limit module. The torque determination module determines a first torque that prevents an engine from stalling. The torque limit module limits engine torque based on the first torque when a driver actuates an accelerator pedal from a first position in which the accelerator pedal is not depressed to a second position in which the accelerator pedal is depressed.

20 Claims, 5 Drawing Sheets





Boost Actuator Module
164
EGR Actuator Module
172
EGR
Wastegate
Exhaust
Electric Motor
198
Hybrid Control Module
196
Phaser Actuator Module
158
Intake Phaser
Exhaust Phaser
134
Spark Actuator Module
126
102
148
150
140
142
122
130
162
Turbo (Hot)
160-1
180
CKP
182
ECT
128
118
170
114
Engine Control Module
120
Cylinder Actuator Module
Transmission Control Module
194
Driver Input
Driver Input Module
104
Fuel Actuator Module
124
110
MAP
184
108
TPS
190
Throttle Actuator Module
116
112
MAF
186
Turbo (Cold)
160-2
183
ATM
IAT
192
Air
100

FIG. 1

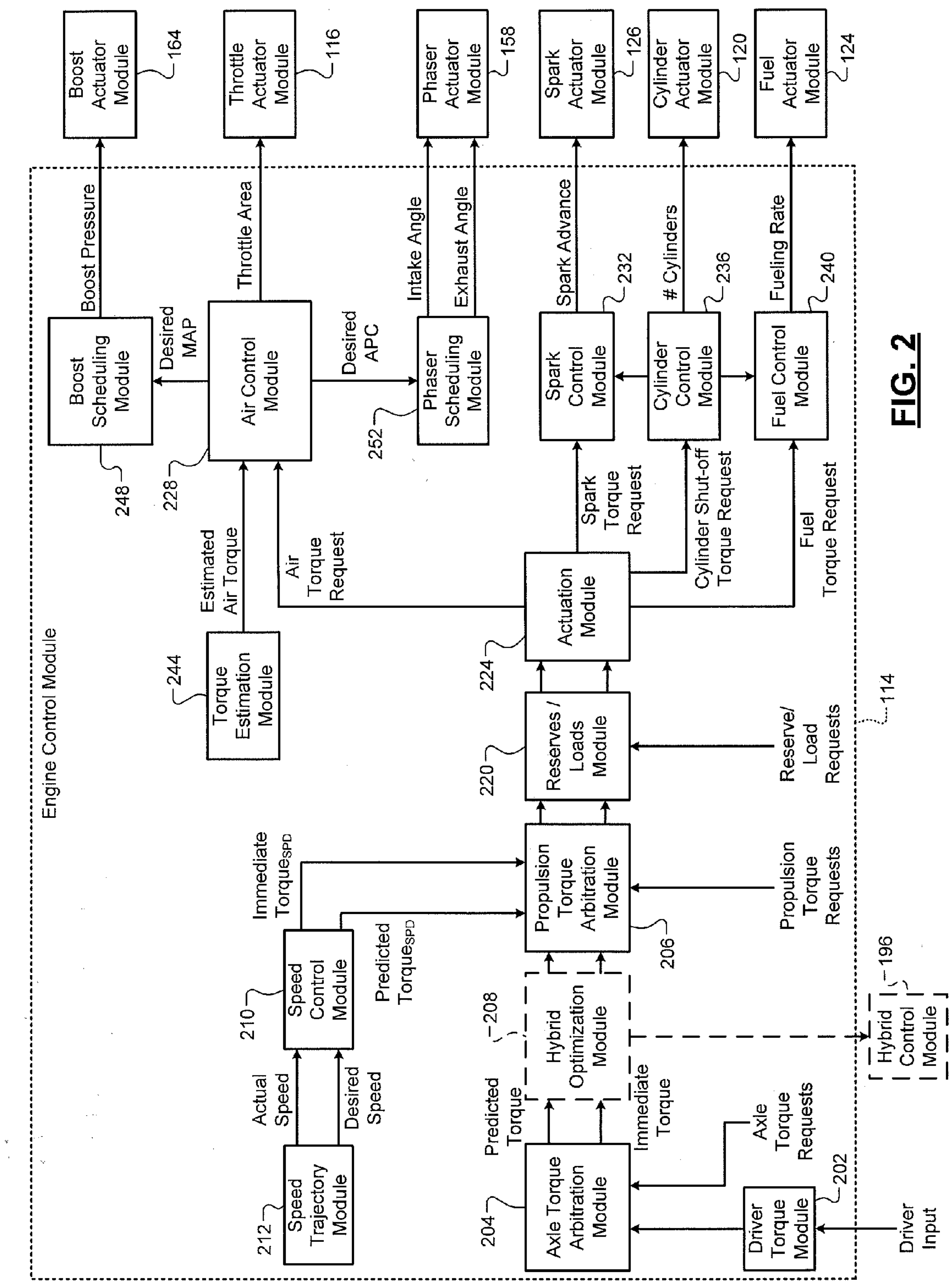

Engine Control Module
114
Boost Actuator Module
164
Throttle Actuator Module
116
Phaser Actuator Module
158
Spark Actuator Module
126
Cylinder Actuator Module
120
Fuel Actuator Module
124
Boost Pressure
Throttle Area
Intake Angle
Exhaust Angle
Spark Advance
Cylinders
Fueling Rate
Boost Scheduling Module
248
Desired MAP
Air Control Module
228
Desired APC
Phaser Scheduling Module
252
Spark Control Module
232
Cylinder Control Module
236
Fuel Control Module
240
Estimated Air Torque
Air Torque Request
Spark Torque Request
Cylinder Shut-off Torque Request
Fuel Torque Request
Torque Estimation Module
244
Actuation Module
224
Reserves / Loads Module
220
Reserve/ Load Requests
Immediate Torque_SPD
Predicted Torque_SPD
Speed Control Module
210
Propulsion Torque Arbitration Module
206
Propulsion Torque Requests
Actual Speed
Desired Speed
Speed Trajectory Module
212
Hybrid Optimization Module
208
Hybrid Control Module
196
Predicted Torque
Immediate Torque
Axle Torque Requests
Axle Torque Arbitration Module
204
Driver Torque Module
202
Driver Input

FIG. 2

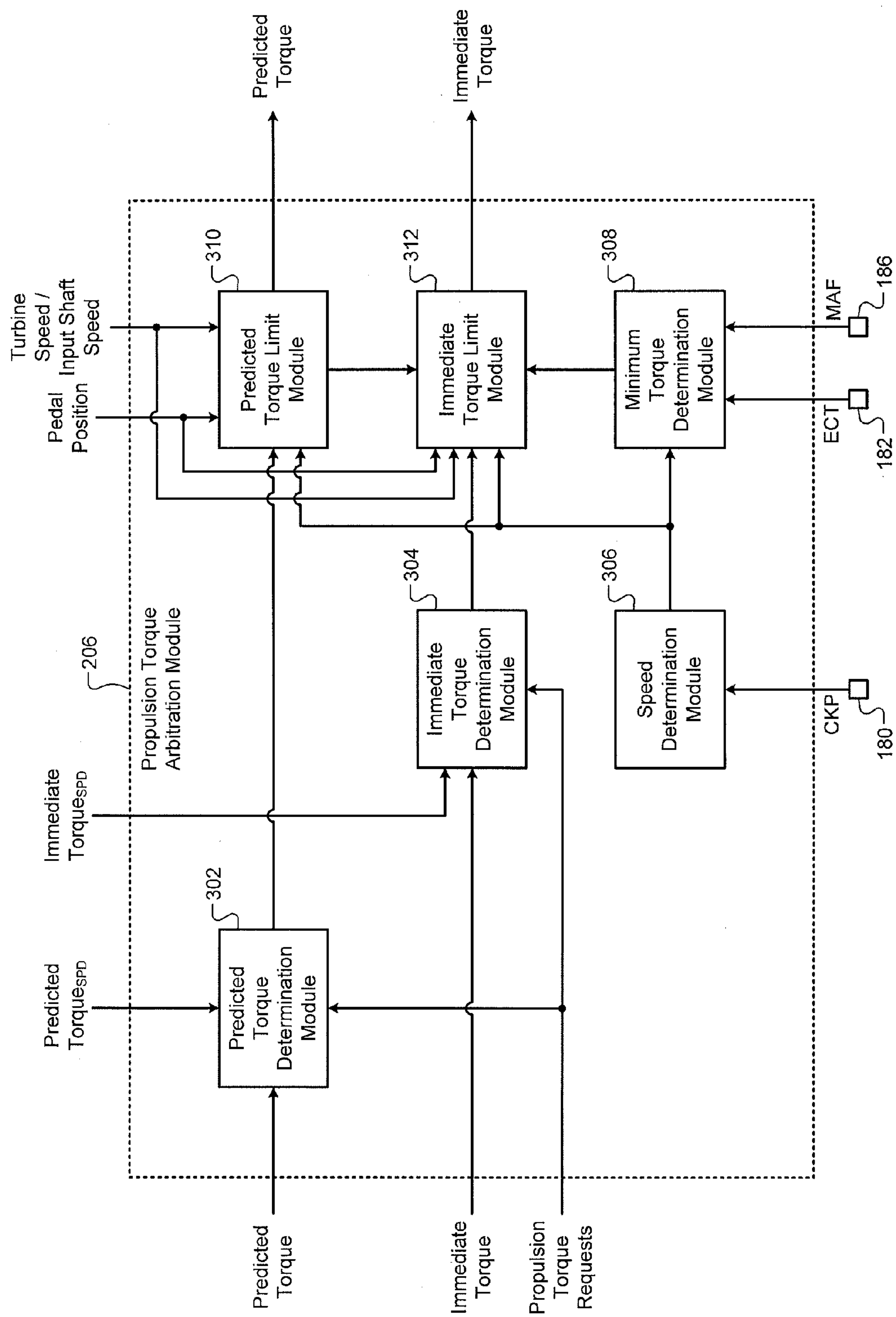
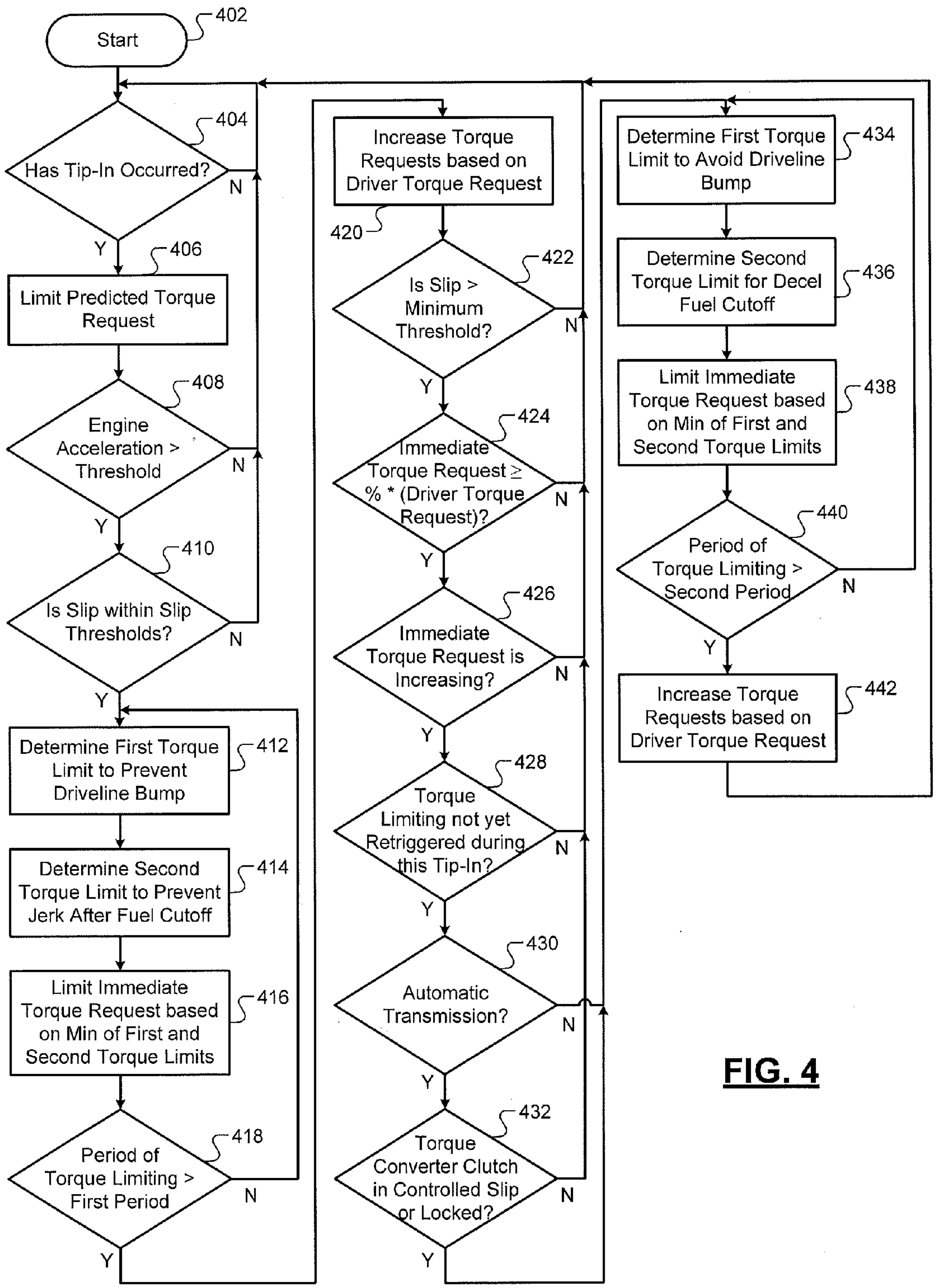
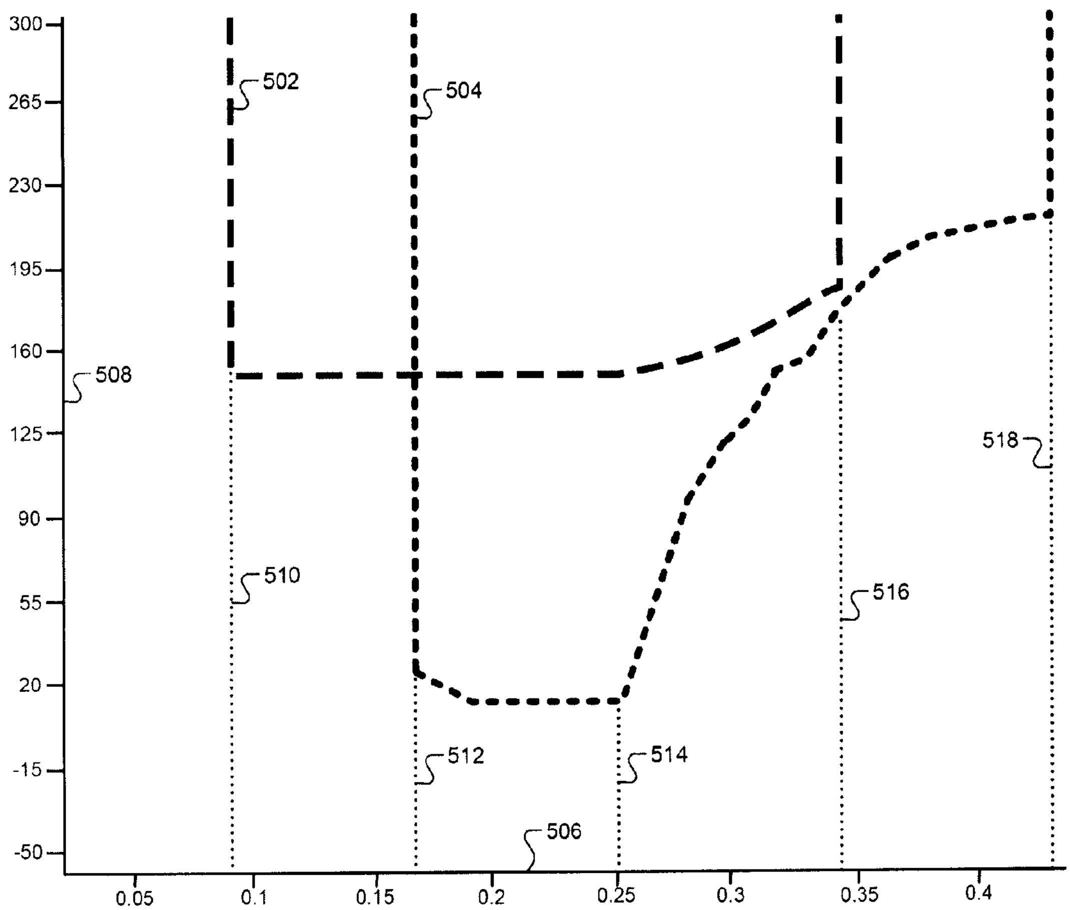

Predicted Torque
Immediate Torque
Turbine Speed / Input Shaft Speed
Pedal Position
310
Predicted Torque Limit Module
312
Immediate Torque Limit Module
308
Minimum Torque Determination Module
MAF
186
ECT
182
206
Propulsion Torque Arbitration Module
304
Immediate Torque Determination Module
306
Speed Determination Module
CKP
180
Immediate Torque$_{SPD}$
Predicted Torque$_{SPD}$
302
Predicted Torque Determination Module
Predicted Torque
Immediate Torque
Propulsion Torque Requests

FIG. 3



Start
402
Has Tip-In Occurred?
404
N
Y
Limit Predicted Torque Request
406
Engine Acceleration > Threshold
408
N
Y
Is Slip within Slip Thresholds?
410
N
Y
Determine First Torque Limit to Prevent Driveline Bump
412
Determine Second Torque Limit to Prevent Jerk After Fuel Cutoff
414
Limit Immediate Torque Request based on Min of First and Second Torque Limits
416
Period of Torque Limiting > First Period
418
N
Y
Increase Torque Requests based on Driver Torque Request
420
Is Slip > Minimum Threshold?
422
N
Y
Immediate Torque Request ≥ % * (Driver Torque Request)?
424
N
Y
Immediate Torque Request is Increasing?
426
N
Y
Torque Limiting not yet Retriggered during this Tip-In?
428
N
Y
Automatic Transmission?
430
N
Y
Torque Converter Clutch in Controlled Slip or Locked?
432
N
Y
Determine First Torque Limit to Avoid Driveline Bump
434
Determine Second Torque Limit for Decel Fuel Cutoff
436
Limit Immediate Torque Request based on Min of First and Second Torque Limits
438
Period of Torque Limiting > Second Period
440
N
Y
Increase Torque Requests based on Driver Torque Request
442

FIG. 4



300
265
230
195
160
125
90
55
20
-15
-50
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
502
504
506
508
510
512
514
516
518

FIG. 5

SYSTEM AND METHOD FOR CONTROLLING ENGINE TORQUE TO PREVENT DRIVELINE BUMP WHEN A DRIVER DEPRESSES AN ACCELERATOR PEDAL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/652,605, filed on May 29, 2012. The disclosure of the above application is incorporated herein by reference in its entirety.

FIELD

The present disclosure relates to systems and methods for preventing driveline bump when a driver depresses an accelerator pedal.

BACKGROUND

The background description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

Internal combustion engines combust an air and fuel mixture within cylinders to drive pistons, which produces drive torque. Air flow into the engine is regulated via a throttle. More specifically, the throttle adjusts the throttle area, which increases or decreases air flow into the engine. As the throttle area increases, the air flow into the engine increases. A fuel control system adjusts the rate that fuel is injected to provide a desired air/fuel mixture to the cylinders and/or to achieve a desired torque output. Increasing the amount of air and fuel provided to the cylinders increases the torque output of the engine.

In spark-ignition engines, spark initiates combustion of an air/fuel mixture provided to the cylinders. In compression-ignition engines, compression in the cylinders combusts the air/fuel mixture provided to the cylinders. Spark timing and air flow may be the primary mechanisms for adjusting the torque output of spark-ignition engines, while fuel flow may be the primary mechanism for adjusting the torque output of compression-ignition engines.

Engine control systems have been developed to control engine output torque to achieve a desired torque. Traditional engine control systems, however, do not control the engine output torque as accurately as desired. Further, traditional engine control systems do not provide a rapid response to control signals or coordinate engine torque control among various devices that affect the engine output torque.

SUMMARY

A system according the principles of the present disclosure includes a torque determination module and a torque limit module. The torque determination module determines a first torque that prevents an engine from stalling. The torque limit module limits engine torque based on the first torque when a driver actuates an accelerator pedal from a first position in which the accelerator pedal is not depressed to a second position in which the accelerator pedal is depressed.

Further areas of applicability of the present disclosure will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. **1** is a functional block diagram of an example engine system according to the principles of the present disclosure;

FIG. **2** is a functional block diagram of an example engine control system according to the principles of the present disclosure;

FIG. **3** is a functional block diagram of an example control module according to the principles of the present disclosure;

FIG. **4** is a flowchart illustrating an example engine control method according to the principles of the present disclosure; and

FIG. **5** is a graph illustrating example torque requests as limited according to the principles of the present disclosure.

DETAILED DESCRIPTION

A manual transmission is directly and mechanically coupled to an engine. An automatic transmission is hydraulically coupled to an engine using a torque converter. Torque converters include an impeller and a turbine. The impeller is mechanically coupled to the engine. The turbine is hydraulically coupled to the impeller and is mechanically coupled to the transmission. Torque converters may also include a lock-up clutch that locks the turbine to the impeller, mechanically coupling the impeller and the turbine.

When an engine produces drive torque, gear teeth on a flywheel of the engine engage gear teeth on a clutch plate of a manual transmission or a torque converter of an automatic transmission. When a vehicle is coasting, the gear teeth on the flywheel may disengage from the gear teeth on the clutch plate, yielding slack in the driveline. When a driver then tips into an accelerator pedal (i.e., depresses an accelerator pedal from a rest position), driveline bump may occur due to slack in the driveline as the gear teeth on the flywheel initially make contact with the gear teeth on the clutch plate. With an automatic transmission, the driveline bump may also be due to a difference between engine speed and turbine speed. With a manual transmission, the driveline bump may also be due to a difference between engine speed and transmission input shaft speed.

An engine control system and method according to the principles of the present disclosure prevents driveline bump by limiting engine torque when a driver tips into an accelerator pedal. Engine torque is limited so that engine speed matches turbine speed or transmission input shaft speed when gear teeth on an engine side initially make contact with gear teeth on a transmission side. Engine torque may be limited based on a minimum torque that prevents an engine from stalling.

As engine torque is limited, the engine torque may be ramped up to a driver torque request. If this ramping is done too quickly, a driver may still feel driveline bump. If this ramping is done too slowly, a driver may notice a delay in vehicle acceleration. Thus, engine torque may be limited based on a balance between preventing driveline bump and preventing acceleration delay.

Referring now to FIG. **1**, a functional block diagram of an example engine system **100** is presented. The engine system **100** includes an engine **102** that combusts an air/fuel mixture to produce drive torque for a vehicle based on driver input from a driver input module **104**. Air is drawn into the engine **102** through an intake system **108**. For example only, the intake system **108** may include an intake manifold **110** and a throttle valve **112**. For example only, the throttle valve **112** may include a butterfly valve having a rotatable blade. An engine control module (ECM) **114** controls a throttle actuator module **116**, which regulates opening of the throttle valve **112** to control the amount of air drawn into the intake manifold **110**.

Air from the intake manifold **110** is drawn into cylinders of the engine **102**. While the engine **102** may include multiple cylinders, for illustration purposes a single representative cylinder **118** is shown. For example only, the engine **102** may include 2, 3, 4, 5, 6, 8, 10, and/or 12 cylinders. The ECM **114** may instruct a cylinder actuator module **120** to selectively deactivate some of the cylinders, which may improve fuel economy under certain engine operating conditions.

The engine **102** may operate using a four-stroke cycle. The four strokes, described below, are named the intake stroke, the compression stroke, the combustion stroke, and the exhaust stroke. During each revolution of a crankshaft (not shown), two of the four strokes occur within the cylinder **118**. Therefore, two crankshaft revolutions are necessary for the cylinder **118** to experience all four of the strokes.

During the intake stroke, air from the intake manifold **110** is drawn into the cylinder **118** through an intake valve **122**. The ECM **114** controls a fuel actuator module **124**, which regulates fuel injection to achieve a desired air/fuel ratio. Fuel may be injected into the intake manifold **110** at a central location or at multiple locations, such as near the intake valve **122** of each of the cylinders. In various implementations (not shown), fuel may be injected directly into the cylinders or into mixing chambers associated with the cylinders. The fuel actuator module **124** may halt injection of fuel to cylinders that are deactivated.

The injected fuel mixes with air and creates an air/fuel mixture in the cylinder **118**. During the compression stroke, a piston (not shown) within the cylinder **118** compresses the air/fuel mixture. The engine **102** may be a compression-ignition engine, in which case compression in the cylinder **118** ignites the air/fuel mixture. Alternatively, the engine **102** may be a spark-ignition engine, in which case a spark actuator module **126** energizes a spark plug **128** in the cylinder **118** based on a signal from the ECM **114**, which ignites the air/fuel mixture. The timing of the spark may be specified relative to the time when the piston is at its topmost position, referred to as top dead center (TDC).

The spark actuator module **126** may be controlled by a timing signal specifying how far before or after TDC to generate the spark. Because piston position is directly related to crankshaft rotation, operation of the spark actuator module **126** may be synchronized with crankshaft angle. In various implementations, the spark actuator module **126** may halt provision of spark to deactivated cylinders.

Generating the spark may be referred to as a firing event. The spark actuator module **126** may have the ability to vary the timing of the spark for each firing event. The spark actuator module **126** may even be capable of varying the spark timing for a next firing event when the spark timing signal is changed between a last firing event and the next firing event.

During the combustion stroke, the combustion of the air/fuel mixture drives the piston down, thereby driving the crankshaft. The combustion stroke may be defined as the time between the piston reaching TDC and the time at which the piston returns to bottom dead center (BDC).

During the exhaust stroke, the piston begins moving up from BDC and expels the byproducts of combustion through an exhaust valve **130**. The byproducts of combustion are exhausted from the vehicle via an exhaust system **134**.

The intake valve **122** may be controlled by an intake camshaft **140**, while the exhaust valve **130** may be controlled by an exhaust camshaft **142**. In various implementations, multiple intake camshafts (including the intake camshaft **140**) may control multiple intake valves (including the intake valve **122**) for the cylinder **118** and/or may control the intake valves (including the intake valve **122**) of multiple banks of cylinders (including the cylinder **118**). Similarly, multiple exhaust camshafts (including the exhaust camshaft **142**) may control multiple exhaust valves for the cylinder **118** and/or may control exhaust valves (including the exhaust valve **130**) for multiple banks of cylinders (including the cylinder **118**).

The cylinder actuator module **120** may deactivate the cylinder **118** by disabling opening of the intake valve **122** and/or the exhaust valve **130**. In various other implementations, the intake valve **122** and/or the exhaust valve **130** may be controlled by devices other than camshafts, such as electromagnetic actuators.

The time at which the intake valve **122** is opened may be varied with respect to piston TDC by an intake cam phaser **148**. The time at which the exhaust valve **130** is opened may be varied with respect to piston TDC by an exhaust cam phaser **150**. A phaser actuator module **158** may control the intake cam phaser **148** and the exhaust cam phaser **150** based on signals from the ECM **114**. When implemented, variable valve lift (not shown) may also be controlled by the phaser actuator module **158**.

The engine system **100** may include a boost device that provides pressurized air to the intake manifold **110**. For example, FIG. **1** shows a turbocharger including a hot turbine **160-1** that is powered by hot exhaust gases flowing through the exhaust system **134**. The turbocharger also includes a cold air compressor **160-2**, driven by the turbine **160-1**, which compresses air leading into the throttle valve **112**. In various implementations, a supercharger (not shown), driven by the crankshaft, may compress air from the throttle valve **112** and deliver the compressed air to the intake manifold **110**.

A wastegate **162** may allow exhaust to bypass the turbine **160-1**, thereby reducing the boost (the amount of intake air compression) of the turbocharger. The ECM **114** may control the turbocharger via a boost actuator module **164**. The boost actuator module **164** may modulate the boost of the turbocharger by controlling the position of the wastegate **162**. In various implementations, multiple turbochargers may be controlled by the boost actuator module **164**. The turbocharger may have variable geometry, which may be controlled by the boost actuator module **164**.

An intercooler (not shown) may dissipate some of the heat contained in the compressed air charge, which is generated as the air is compressed. The compressed air charge may also have absorbed heat from components of the exhaust system **134**. Although shown separated for purposes of illustration, the turbine **160-1** and the compressor **160-2** may be attached to each other, placing intake air in close proximity to hot exhaust.

The engine system **100** may include an exhaust gas recirculation (EGR) valve **170**, which selectively redirects exhaust gas back to the intake manifold **110**. The EGR valve **170** may be located upstream of the turbocharger's turbine **160-1**. The EGR valve **170** may be controlled by an EGR actuator module **172**.

The engine system **100** may measure the position of the crankshaft using a crankshaft position (CKP) sensor **180**. The ECM **114** may use the crankshaft position to calculate engine speed in, for example, revolutions per minute (rpm). The temperature of the engine coolant may be measured using an engine coolant temperature (ECT) sensor **182**. The ECT sensor **182** may be located within the engine **102** or at other locations where the coolant is circulated, such as a radiator (not shown).

Atmospheric pressure may be measured using an atmospheric pressure (ATM) sensor **183**. The pressure within the intake manifold **110** may be measured using a manifold absolute pressure (MAP) sensor **184**. In various implementations, engine vacuum, which is the difference between the ambient air pressure and the pressure within the intake manifold **110**, may be measured. The mass flow rate of air flowing into the intake manifold **110** may be measured using a mass air flow (MAF) sensor **186**. In various implementations, the MAF sensor **186** may be located in a housing that also includes the throttle valve **112**.

The throttle actuator module **116** may monitor the position of the throttle valve **112** using one or more throttle position sensors (TPS) **190**. The ambient temperature of air being drawn into the engine **102** may be measured using an intake air temperature (IAT) sensor **192**. The ECM **114** may use signals from the sensors to make control decisions for the engine system **100**.

The ECM **114** may communicate with a transmission control module (TCM) **194** to coordinate shifting gears in a transmission (not shown). For example, the ECM **114** may reduce engine torque during a gear shift. The ECM **114** may communicate with a hybrid control module (HCM) **196** to coordinate operation of the engine **102** and an electric motor **198**.

The electric motor **198** may also function as a generator, and may be used to produce electrical energy for use by vehicle electrical systems and/or for storage in a battery. In various implementations, various functions of the ECM **114**, the TCM **194**, and the HCM **196** may be integrated into one or more modules.

Each system that varies an engine parameter may be referred to as an actuator that receives an actuator value. For example, the throttle actuator module **116** may be referred to as an actuator and the throttle opening area may be referred to as the actuator value. In the example of FIG. **1**, the throttle actuator module **116** achieves the throttle opening area by adjusting an angle of the blade of the throttle valve **112**.

Similarly, the spark actuator module **126** may be referred to as an actuator, while the corresponding actuator value may be the amount of spark advance relative to cylinder TDC. Other actuators may include the cylinder actuator module **120**, the fuel actuator module **124**, the phaser actuator module **158**, the boost actuator module **164**, and the EGR actuator module **172**. For these actuators, the actuator values may correspond to number of activated cylinders, fueling rate, intake and exhaust cam phaser angles, boost pressure, and EGR valve opening area, respectively. The ECM **114** may control actuator values in order to cause the engine **102** to generate a desired engine output torque.

Referring now to FIG. **2**, a functional block diagram of an example engine control system is presented. An example implementation of the ECM **114** includes a driver torque module **202**. The driver torque module **202** may determine a driver torque request based on a driver input from the driver input module **104**. The driver input may be based on a position of an accelerator pedal. The driver input may also be based on cruise control, which may be an adaptive cruise control system that varies vehicle speed to maintain a predetermined following distance. The driver torque module **202** may store one or more mappings of accelerator pedal position to desired torque, and may determine the driver torque request based on a selected one of the mappings.

An axle torque arbitration module **204** arbitrates between the driver torque request from the driver torque module **202** and other axle torque requests. Axle torque (torque at the wheels) may be produced by various sources including an engine and/or an electric motor. Torque requests may include absolute torque requests as well as relative torque requests and ramp requests. For example only, ramp requests may include a request to ramp torque down to a minimum engine off torque or to ramp torque up from the minimum engine off torque. Relative torque requests may include temporary or persistent torque reductions or increases.

Axle torque requests may include a torque reduction requested by a traction control system when positive wheel slip is detected. Positive wheel slip occurs when axle torque overcomes friction between the wheels and the road surface, and the wheels begin to slip against the road surface. Axle torque requests may also include a torque increase request to counteract negative wheel slip, where a tire of the vehicle slips with respect to the road surface because the axle torque is negative.

Axle torque requests may also include brake management requests and vehicle over-speed torque requests. Brake management requests may reduce axle torque to ensure that the axle torque does not exceed the ability of the brakes to hold the vehicle when the vehicle is stopped. Vehicle over-speed torque requests may reduce the axle torque to prevent the vehicle from exceeding a predetermined speed. Axle torque requests may also be generated by vehicle stability control systems.

The axle torque arbitration module **204** outputs a predicted torque request and an immediate torque request based on the results of arbitrating between the received torque requests. As described below, the predicted and immediate torque requests from the axle torque arbitration module **204** may selectively be adjusted by other modules of the ECM **114** before being used to control actuators of the engine system **100**.

In general terms, the immediate torque request is the amount of currently desired axle torque, while the predicted torque request is the amount of axle torque that may be needed on short notice. The ECM **114** therefore controls the engine system **100** to produce an axle torque equal to the immediate torque request. However, different combinations of actuator values may result in the same axle torque. The ECM **114** may therefore adjust the actuator values to allow a faster transition to the predicted torque request, while still maintaining the axle torque at the immediate torque request.

In various implementations, the predicted torque request may be based on the driver torque request. The immediate torque request may be less than the predicted torque request, such as when the driver torque request is causing wheel slip on an icy surface. In such a case, a traction control system (not shown) may request a reduction via the immediate torque request, and the ECM **114** reduces the torque produced by the engine system **100** to the immediate torque request. However, the ECM **114** controls the engine system **100** so that the engine system **100** can quickly resume producing the predicted torque request once the wheel slip stops.

In general terms, the difference between the immediate torque request and the higher predicted torque request can be referred to as a torque reserve. The torque reserve may represent the amount of additional torque that the engine system **100** can begin to produce with minimal delay. Fast engine actuators are used to increase or decrease current axle torque. As described in more detail below, fast engine actuators are defined in contrast with slow engine actuators.

In various implementations, fast engine actuators are capable of varying axle torque within a range, where the range is established by the slow engine actuators. In such implementations, the upper limit of the range is the predicted torque request, while the lower limit of the range is limited by the torque capacity of the fast actuators. For example only, fast actuators may only be able to reduce axle torque by a first amount, where the first amount is a measure of the torque capacity of the fast actuators. The first amount may vary based on engine operating conditions set by the slow engine actuators. When the immediate torque request is within the range, fast engine actuators can be set to cause the axle torque to be equal to the immediate torque request. When the ECM **114** requests the predicted torque request to be output, the fast engine actuators can be controlled to vary the axle torque to the top of the range, which is the predicted torque request.

In general terms, fast engine actuators can more quickly change the axle torque when compared to slow engine actuators. Slow actuators may respond more slowly to changes in their respective actuator values than fast actuators do. For example, a slow actuator may include mechanical components that require time to move from one position to another in response to a change in actuator value. A slow actuator may also be characterized by the amount of time it takes for the axle torque to begin to change once the slow actuator begins to implement the changed actuator value. Generally, this amount of time will be longer for slow actuators than for fast actuators. In addition, even after beginning to change, the axle torque may take longer to fully respond to a change in a slow actuator.

For example only, the ECM **114** may set actuator values for slow actuators to values that would enable the engine system **100** to produce the predicted torque request if the fast actuators were set to appropriate values. Meanwhile, the ECM **114** may set actuator values for fast actuators to values that, given the slow actuator values, cause the engine system **100** to produce the immediate torque request instead of the predicted torque request.

The fast actuator values therefore cause the engine system **100** to produce the immediate torque request. When the ECM **114** decides to transition the axle torque from the immediate torque request to the predicted torque request, the ECM **114** changes the actuator values for one or more fast actuators to values that correspond to the predicted torque request. Because the slow actuator values have already been set based on the predicted torque request, the engine system **100** is able to produce the predicted torque request after only the delay imposed by the fast actuators. In other words, the longer delay that would otherwise result from changing axle torque using slow actuators is avoided.

For example only, when the predicted torque request is equal to the driver torque request, a torque reserve may be created when the immediate torque request is less than the driver torque request due to a temporary torque reduction request. Alternatively, a torque reserve may be created by increasing the predicted torque request above the driver torque request while maintaining the immediate torque request at the driver torque request. The resulting torque reserve can absorb sudden increases in required axle torque. For example only, sudden loads from an air conditioner or a power steering pump may be counterbalanced by increasing the immediate torque request. If the increase in immediate torque request is less than the torque reserve, the increase can be quickly produced by using fast actuators. The predicted torque request may then also be increased to re-establish the previous torque reserve.

Another example use of a torque reserve is to reduce fluctuations in slow actuator values. Because of their relatively slow speed, varying slow actuator values may produce control instability. In addition, slow actuators may include mechanical parts, which may draw more power and/or wear more quickly when moved frequently. Creating a sufficient torque reserve allows changes in desired torque to be made by varying fast actuators via the immediate torque request while maintaining the values of the slow actuators. For example, to maintain a given idle speed, the immediate torque request may vary within a range. If the predicted torque request is set to a level above this range, variations in the immediate torque request that maintain the idle speed can be made using fast actuators without the need to adjust slow actuators.

For example only, in a spark-ignition engine, spark timing may be a fast actuator value, while throttle opening area may be a slow actuator value. Spark-ignition engines may combust fuels including, for example, gasoline and ethanol, by applying a spark. By contrast, in a compression-ignition engine, fuel flow may be a fast actuator value, while throttle opening area may be used as an actuator value for engine characteristics other than torque. Compression-ignition engines may combust fuels including, for example, diesel, by compressing the fuels.

When the engine **102** is a spark-ignition engine, the spark actuator module **126** may be a fast actuator and the throttle actuator module **116** may be a slow actuator. After receiving a new actuator value, the spark actuator module **126** may be able to change spark timing for the following firing event. When the spark timing (also called spark advance) for a firing event is set to a calibrated value, maximum torque is produced in the combustion stroke immediately following the firing event. However, a spark advance deviating from the calibrated value may reduce the amount of torque produced in the combustion stroke. Therefore, the spark actuator module **126** may be able to vary engine output torque as soon as the next firing event occurs by varying spark advance. For example only, a table of spark advances corresponding to different engine operating conditions may be determined during a calibration phase of vehicle design, and the calibrated value is selected from the table based on current engine operating conditions.

By contrast, changes in throttle opening area take longer to affect engine output torque. The throttle actuator module **116** changes the throttle opening area by adjusting the angle of the blade of the throttle valve **112**. Therefore, once a new actuator value is received, there is a mechanical delay as the throttle valve **112** moves from its previous position to a new position based on the new actuator value. In addition, air flow changes based on the throttle valve opening are subject to air transport delays in the intake manifold **110**. Further, increased air flow in the intake manifold **110** is not realized as an increase in engine output torque until the cylinder **118** receives additional air in the next intake stroke, compresses the additional air, and commences the combustion stroke.

Using these actuators as an example, a torque reserve can be created by setting the throttle opening area to a value that would allow the engine **102** to produce a predicted torque request. Meanwhile, the spark timing can be set based on an immediate torque request that is less than the predicted torque request. Although the throttle opening area generates enough air flow for the engine **102** to produce the predicted torque request, the spark timing is retarded (which reduces torque) based on the immediate torque request. The engine output torque will therefore be equal to the immediate torque request.

When additional torque is needed, such as when the air conditioning compressor is started, or when traction control determines wheel slip has ended, the spark timing can be set based on the predicted torque request. By the following firing event, the spark actuator module **126** may return the spark advance to a calibrated value, which allows the engine **102** to produce the full engine output torque achievable with the air flow already present. The engine output torque may therefore be quickly increased to the predicted torque request without experiencing delays from changing the throttle opening area.

When the engine **102** is a compression-ignition engine, the fuel actuator module **124** may be a fast actuator and the throttle actuator module **116** and the boost actuator module **164** may be emissions actuators. In this manner, the fuel mass may be set based on the immediate torque request, and the throttle opening area and boost may be set based on the predicted torque request. The throttle opening area may generate more air flow than necessary to satisfy the predicted torque request. In turn, the air flow generated may be more than required for complete combustion of the injected fuel such that the air/fuel ratio is usually lean and changes in air flow do not affect the engine torque output. The engine output torque will therefore be equal to the immediate torque request and may be increased or decreased by adjusting the fuel flow.

The throttle actuator module **116**, the boost actuator module **164**, and the EGR actuator module **172** may be controlled based on the predicted torque request to control emissions and to minimize turbo lag. The throttle actuator module **116** may create a vacuum to draw exhaust gases through the EGR valve **170** and into the intake manifold **110**.

The axle torque arbitration module **204** may output the predicted torque request and the immediate torque request to a propulsion torque arbitration module **206**. In various implementations, the axle torque arbitration module **204** may output the predicted and immediate torque requests to a hybrid optimization module **208**. The hybrid optimization module **208** determines how much torque should be produced by the engine **102** and how much torque should be produced by the electric motor **198**. The hybrid optimization module **208** then outputs modified predicted and immediate torque requests to the propulsion torque arbitration module **206**. In various implementations, the hybrid optimization module **208** may be implemented in the HCM **196**.

The predicted and immediate torque requests received by the propulsion torque arbitration module **206** are converted from an axle torque domain (torque at the wheels) into a propulsion torque domain (torque at the crankshaft). This conversion may occur before, after, as part of, or in place of the hybrid optimization module **208**.

The propulsion torque arbitration module **206** arbitrates between propulsion torque requests, including the converted predicted and immediate torque requests. The propulsion torque arbitration module **206** generates an arbitrated predicted torque request and an arbitrated immediate torque request. The arbitrated torques may be generated by selecting a winning request from among received requests. Alternatively or additionally, the arbitrated torques may be generated by modifying one of the received requests based on another one or more of the received requests.

Other propulsion torque requests may include torque reductions for engine over-speed protection, torque increases for stall prevention, and torque reductions requested by the TCM **194** to accommodate gear shifts. Propulsion torque requests may also result from clutch fuel cutoff, which reduces the engine output torque when the driver depresses the clutch pedal in a manual transmission vehicle to prevent a flare (rapid rise) in engine speed.

Propulsion torque requests may also include an engine shutoff request, which may be initiated when a critical fault is detected. For example only, critical faults may include detection of vehicle theft, a stuck starter motor, electronic throttle control problems, and unexpected torque increases. In various implementations, when an engine shutoff request is present, arbitration selects the engine shutoff request as the winning request. When the engine shutoff request is present, the propulsion torque arbitration module **206** may output zero as the arbitrated torques.

In various implementations, an engine shutoff request may simply shut down the engine **102** separately from the arbitration process. The propulsion torque arbitration module **206** may still receive the engine shutoff request so that, for example, appropriate data can be fed back to other torque requestors. For example, all other torque requestors may be informed that they have lost arbitration.

A speed control module **210** may also output predicted and immediate torque requests to the propulsion torque arbitration module **206**. The torque requests from the speed control module **210** may prevail in arbitration when the ECM **114** is in a speed mode. Speed mode may be enabled when the driver removes their foot from the accelerator pedal, such as when the engine **102** is idling or when the vehicle is coasting down from a higher speed. Alternatively or additionally, speed mode may be enabled when the predicted torque request from the axle torque arbitration module **204** is less than a predetermined torque value.

The speed control module **210** receives an actual speed and a desired speed from a speed trajectory module **212** and controls the predicted and immediate torque requests to reduce the difference between the actual speed and the desired speed. For example only, the speed trajectory module **212** may output a linearly decreasing desired speed for vehicle coastdown until an idle speed is reached. The speed trajectory module **212** may then continue outputting the idle speed as the desired speed. In the preceding example, the linearly decreasing desired speed may be referred to as a reference speed and the idle speed may be referred to as the desired speed. The speed control module **210** may receive both the reference speed and the desired speed from the speed trajectory module **212**.

A reserves/loads module **220** receives the arbitrated predicted and immediate torque requests from the propulsion torque arbitration module **206**. The reserves/loads module **220** may adjust the arbitrated predicted and immediate torque requests to create a torque reserve and/or to compensate for one or more loads. The reserves/loads module **220** then outputs the adjusted predicted and immediate torque requests to an actuation module **224**. The actuation module **224** may be referred to as a torque control module.

For example only, a catalyst light-off process or a cold start emissions reduction process may require retarded spark advance. The reserves/loads module **220** may therefore increase the adjusted predicted torque request above the adjusted immediate torque request to create retarded spark for the cold start emissions reduction process. In another example, the air/fuel ratio of the engine and/or the mass air flow may be directly varied, such as by diagnostic intrusive equivalence ratio testing and/or new engine purging. Before beginning these processes, a torque reserve may be created or increased to quickly offset decreases in engine output torque that result from leaning the air/fuel mixture during these processes.

The reserves/loads module **220** may also create or increase a torque reserve in anticipation of a future load, such as power steering pump operation or engagement of an air conditioning (NC) compressor clutch. The reserve for engagement of the A/C compressor clutch may be created when the driver first requests air conditioning. The reserves/loads module **220** may increase the adjusted predicted torque request while leaving the adjusted immediate torque request unchanged to produce the torque reserve. Then, when the A/C compressor clutch engages, the reserves/loads module **220** may increase the immediate torque request by the estimated load of the A/C compressor clutch.

The actuation module **224** receives the adjusted predicted and immediate torque requests from the reserves/loads module **220**. The actuation module **224** determines how the adjusted predicted and immediate torque requests will be achieved. The actuation module **224** may be engine type specific. For example, the actuation module **224** may be implemented differently or use different control schemes for spark-ignition engines versus compression-ignition engines.

In various implementations, the actuation module **224** may define a boundary between modules that are common across all engine types and modules that are engine type specific. For example, engine types may include spark-ignition and compression-ignition. Modules prior to the actuation module **224**, such as the propulsion torque arbitration module **206**, may be common across engine types, while the actuation module **224** and subsequent modules may be engine type specific.

For example, in a spark-ignition engine, the actuation module **224** may vary the opening of the throttle valve **112** as a slow actuator that allows for a wide range of torque control. The actuation module **224** may disable cylinders using the cylinder actuator module **120**, which also provides for a wide range of torque control but may also be slow and may involve drivability and emissions concerns. The actuation module **224** may use spark timing as a fast actuator. However, spark timing may not provide as much range of torque control. In addition, the amount of torque control possible with changes in spark timing (referred to as spark reserve capacity) may vary as air flow changes.

In various implementations, the actuation module **224** may generate an air torque request based on the adjusted predicted torque request. The air torque request may be equal to the adjusted predicted torque request, setting air flow so that the adjusted predicted torque request can be achieved by changes to other actuators.

An air control module **228** may determine desired actuator values based on the air torque request. For example, the air control module **228** may control desired manifold absolute pressure (MAP), desired throttle area, and/or desired air per cylinder (APC). Desired MAP may be used to determine desired boost, and desired APC may be used to determine desired cam phaser positions. In various implementations, the air control module **228** may also determine an amount of opening of the EGR valve **170**.

The actuation module **224** may also generate a spark torque request, a cylinder shut-off torque request, and a fuel torque request. The spark torque request may be used by a spark control module **232** to determine how much to retard the spark timing (which reduces engine output torque) from a calibrated spark advance.

The cylinder shut-off torque request may be used by a cylinder control module **236** to determine how many cylinders to deactivate. The cylinder control module **236** may instruct the cylinder actuator module **120** to deactivate one or more cylinders of the engine **102**. In various implementations, a predefined group of cylinders may be deactivated jointly.

The cylinder control module **236** may also instruct a fuel control module **240** to stop providing fuel for deactivated cylinders and may instruct the spark control module **232** to stop providing spark for deactivated cylinders. In various implementations, the spark control module **232** only stops providing spark for a cylinder once any fuel/air mixture already present in the cylinder has been combusted.

In various implementations, the cylinder actuator module **120** may include a hydraulic system that selectively decouples intake and/or exhaust valves from the corresponding camshafts for one or more cylinders in order to deactivate those cylinders. For example only, valves for half of the cylinders are either hydraulically coupled or decoupled as a group by the cylinder actuator module **120**. In various implementations, cylinders may be deactivated simply by halting provision of fuel to those cylinders without stopping the opening and closing of the intake and exhaust valves. In such implementations, the cylinder actuator module **120** may be omitted.

The fuel control module **240** may vary the amount of fuel provided to each cylinder based on the fuel torque request from the actuation module **224**. During normal operation of a spark-ignition engine, the fuel control module **240** may operate in an air lead mode in which the fuel control module **240** attempts to maintain a stoichiometric air/fuel ratio by controlling fuel flow based on air flow. The fuel control module **240** may determine a fuel mass that will yield stoichiometric combustion when combined with the current amount of air per cylinder. The fuel control module **240** may instruct the fuel actuator module **124** via the fueling rate to inject this fuel mass for each activated cylinder.

In compression-ignition systems, the fuel control module **240** may operate in a fuel lead mode in which the fuel control module **240** determines a fuel mass for each cylinder that satisfies the fuel torque request while minimizing emissions, noise, and fuel consumption. In the fuel lead mode, air flow is controlled based on fuel flow and may be controlled to yield a lean air/fuel ratio. In addition, the air/fuel ratio may be maintained above a predetermined level, which may prevent black smoke production in dynamic engine operating conditions.

A mode setting may determine how the actuation module **224** treats the adjusted immediate torque request. The mode setting may be provided to the actuation module **224**, such as by the propulsion torque arbitration module **206**, and may select modes including an inactive mode, a pleasible mode, a maximum range mode, and an auto actuation mode.

In the inactive mode, the actuation module **224** may ignore the adjusted immediate torque request and set engine output torque based on the adjusted predicted torque request. The actuation module **224** may therefore set the spark torque request, the cylinder shut-off torque request, and the fuel torque request to the adjusted predicted torque request, which maximizes engine output torque for the current engine air flow conditions. Alternatively, the actuation module **224** may set these requests to predetermined (such as out-of-range high) values to disable torque reductions from retarding spark, deactivating cylinders, or reducing the fuel/air ratio.

In the pleasible mode, the actuation module **224** outputs the adjusted predicted torque request as the air torque request and attempts to achieve the adjusted immediate torque request by adjusting only spark advance. The actuation module **224** therefore outputs the adjusted immediate torque request as the spark torque request. The spark control module **232** will retard the spark as much as possible to attempt to achieve the spark torque request. If the desired torque reduction is greater than the spark reserve capacity (the amount of torque reduction achievable by spark retard), the torque reduction may not be achieved. The engine output torque will then be greater than the adjusted immediate torque request.

In the maximum range mode, the actuation module **224** may output the adjusted predicted torque request as the air torque request and the adjusted immediate torque request as the spark torque request. In addition, the actuation module **224** may decrease the cylinder shut-off torque request (thereby deactivating cylinders) when reducing spark advance alone is unable to achieve the adjusted immediate torque request.

In the auto actuation mode, the actuation module **224** may decrease the air torque request based on the adjusted immediate torque request. In various implementations, the air torque request may be reduced only so far as is necessary to allow the spark control module **232** to achieve the adjusted immediate torque request by adjusting spark advance. Therefore, in auto actuation mode, the adjusted immediate torque request is achieved while adjusting the air torque request as little as possible. In other words, the use of relatively slowly-responding throttle valve opening is minimized by reducing the quickly-responding spark advance as much as possible. This allows the engine **102** to return to producing the adjusted predicted torque request as quickly as possible.

A torque estimation module **244** may estimate torque output of the engine **102**. This estimated torque may be used by the air control module **228** to perform closed-loop control of engine air flow parameters, such as throttle area, MAP, and phaser positions. For example, a torque relationship such as

$$T=f(\mathrm{APC},S,I,E,\mathrm{AF},\mathrm{OT},\#) \tag{1}$$

may be defined, where torque (T) is a function of air per cylinder (APC), spark advance (S), intake cam phaser position (I), exhaust cam phaser position (E), air/fuel ratio (AF), oil temperature (OT), and number of activated cylinders (#). Additional variables may also be accounted for, such as the degree of opening of an exhaust gas recirculation (EGR) valve.

This relationship may be modeled by an equation and/or may be stored as a lookup table. The torque estimation module **244** may determine APC based on the measured MAF and the actual engine speed, thereby allowing closed loop air control based on actual air flow. The intake and exhaust cam phaser positions used may be based on actual positions, as the phasers may be traveling toward desired positions.

The actual spark advance may be used to estimate the actual engine output torque. When a calibrated spark advance value is used to estimate torque, the estimated torque may be called an estimated air torque, or simply air torque. The air torque is an estimate of how much torque the engine could generate at the current air flow if spark retard was removed (i.e., spark timing was set to the calibrated spark advance value) and all cylinders were fueled.

The air control module **228** may output a desired throttle area to the throttle actuator module **116**. The throttle actuator module **116** then regulates the throttle valve **112** to produce the desired throttle area. The air control module **228** may determine the desired throttle area based on an inverse torque model and the air torque request. The air control module **228** may use the estimated air torque and/or the MAF signal in order to perform closed loop control. For example, the desired throttle area may be controlled to minimize a difference between the estimated air torque and the air torque request.

The air control module **228** may output a desired manifold absolute pressure (MAP) signal to a boost scheduling module **248**. The boost scheduling module **248** uses the desired MAP signal to control the boost actuator module **164**. The boost actuator module **164** then controls one or more turbochargers (e.g., the turbocharger including the turbine **160-1** and the compressor **160-2**) and/or superchargers.

The air control module **228** may also output a desired air per cylinder (APC) signal to a phaser scheduling module **252**. Based on the desired APC signal and the actual engine speed, the phaser scheduling module **252** may control positions of the intake and/or exhaust cam phasers **148** and **150** using the phaser actuator module **158**.

Referring back to the spark control module **232**, calibrated spark advance values may vary based on various engine operating conditions. For example only, a torque relationship may be inverted to solve for desired spark advance. For a given torque request (T_{des}), the desired spark advance (S_{des}) may be determined based on

$$S_{des}=f(T_{des},\mathrm{APC},I,E,\mathrm{AF},\mathrm{OT},\#) \tag{2}$$

This relationship may be embodied as an equation and/or as a lookup table. The air/fuel ratio may be the actual air/fuel ratio, as reported by the fuel control module **240**.

When the spark advance is set to the calibrated spark advance, the resulting torque may be as close to mean best torque (MBT) as possible. MBT refers to the maximum engine output torque that is generated for a given air flow as spark advance is increased, while using fuel having an octane rating greater than a predetermined threshold and using stoichiometric fueling. The spark advance at which this maximum torque occurs is referred to as MBT spark. The calibrated spark advance may differ slightly from MBT spark because of, for example, fuel quality (such as when lower octane fuel is used) and environmental factors. The torque at the calibrated spark advance may therefore be less than MBT.

Referring now to FIG. **3**, the propulsion torque arbitration module **206** may include a predicted torque determination module **302** and an immediate torque determination module **304**. The predicted torque determination module **302** and the immediate torque determination module **304** determine a predicted torque request and an immediate torque request, respectively. The torque determination modules **302**, **304** may determine the predicted and immediate torque requests by arbitrating between various propulsion torque requests. The propulsion torque requests may include those converted from axle torque requests output by the axle torque arbitration module **204**, those from the speed control module **210**, and other propulsion torque requests, as discussed above with reference to FIG. **2**. The torque determination modules **302**, **304** output the predicted and immediate torque requests.

A speed determination module **306** determines the actual speed of the engine **102** based on the crankshaft position from the CKP sensor **180**. For example, the speed determination module **306** may calculate the engine speed based on a period that elapses as the crankshaft completes one or more revolutions. The speed determination module **306** outputs the engine speed. The speed determination module **306** may also determine engine acceleration (i.e., the rate of change of engine speed) and output the engine acceleration.

A minimum torque determination module **308** determines a minimum torque that prevents the engine **102** from stalling. The minimum torque may be a minimum amount of torque that can be produced by the engine **102** with minimal spark advance while keeping the engine **102** running and maintaining stable combustion. The minimum torque determination module **308** may determine the minimum torque based on the actual speed of the engine **102** and the mass flow rate of intake air from the MAF sensor **186** using, for example, a lookup table. Other engine operating conditions that may be used to determine the minimum torque include those that affect the combustibility of fuel such as the engine coolant temperature from the ECT sensor **182**. The minimum torque determination module **308** outputs the minimum torque.

A predicted torque limit module **310** and an immediate torque limit module **312** selectively limit the predicted torque request and the immediate torque request, respectively, which are output by the torque determination modules **302**, **304**. The predicted torque limit module **310** module may limit the predicted torque request when a driver tips into an accelerator pedal (i.e., depresses an accelerator pedal from a released position). The predicted torque limit module **310** module may limit the predicted torque request when the percentage of pedal depression is greater than a threshold (e.g., 0 percent) and/or when the period of pedal depression is less than a threshold (e.g., 0.6 seconds). The predicted torque limit module **310** may determine the percentage and period of pedal depression based on pedal position, which may be received from the driver input module **104** of FIG. **1**.

The immediate torque limit module **312** may not limit the immediate torque request when the predicted torque limit module **310** limits the predicted torque request until other conditions are satisfied, indicating that driveline bump is likely to occur. Driveline bump may be likely to occur when the engine speed continues to increase despite limiting the predicted torque request. When the predicted torque request is limited but the immediate torque request is not limited, the operating mode of the ECM **114** may be referred to as an enabled mode.

The immediate torque limit module **312** may limit the immediate torque request after a tip-in when the engine acceleration is greater than an acceleration threshold (e.g., 400 rpm/second) and slip is within slip thresholds. For an automatic transmission, slip is the difference between the engine speed and a turbine speed. For a manual transmission, slip is the difference between the engine speed and a transmission input shaft speed. The immediate torque limit module **312** may receive the turbine speed and/or the transmission input shaft speed from the TCM **194** of FIG. **1**. When the immediate torque limit module **312** initially limits the immediate torque request, the operating mode of the ECM **114** may be referred to as an activated mode.

The slip thresholds may include a minimum threshold (e.g., 60 rpm) and a maximum threshold (e.g., 500 rpm). The slip may be within the slip thresholds when the slip is greater than the minimum threshold, indicating a potential for driveline bump, and less than the maximum threshold. When the slip is greater than the maximum threshold, the driver may be executing an aggressive maneuver, in which case it may be undesirable to interfere with the driver torque request.

When operating in the activated mode, the torque limits modules **310**, **312** may decrease the predicted and immediate torque requests and then increase the predicted and immediate torque requests in a manner that prevents driveline bump. The predicted torque limit module **310** may initially set the predicted torque request to the estimated torque determined using relationship (1), discussed above with reference to FIG. **2**. The estimated torque may be less than the driver torque request.

After setting the predicted torque request to the estimated torque, the predicted torque limit module **310** may increase the predicted torque request by a predetermined rate. For example, the predicted torque limit module **310** may increase the predicted torque request by 5 Newton-meters (Nm) every 12.5 milliseconds (ms). The predicted torque limit module **310** may increase the predicted torque request by the predetermined rate until the ECM **114** is no longer operating in the activated mode.

When operating in the activated mode, the immediate torque limit module **312** may limit the immediate torque request based on the minimum torque. For example, the immediate torque limit module **312** may set the immediate torque request equal to the sum of the minimum torque and a torque offset. Adjusting the immediate torque request in this manner ensures that the immediate torque request increases as the minimum torque increases. The torque offset may be determined based on a current transmission gear and a desired engine speed using, for example, a lookup table.

The ECM **114** may operate in the activated mode for a predetermined period (e.g., 100 ms). When the predetermined period expires, the torque limit modules **310**, **312** may increase the predicted and immediate torque requests based on the driver torque request. The predicted torque limit module **310** may increase the predicted torque request to the driver torque request. The immediate torque limit module **312** may increase the immediate torque request to the driver torque request minus a torque reserve. The torque limit modules **310**, **312** may increase the predicted and immediate torque requests in a nonlinear manner. When the torque limit modules **310**, **312** increase the predicted and immediate torque requests based on the driver torque request, the operating mode of the ECM **114** may be referred to as a disabled mode.

When operating in the disabled mode, the torque limit modules **310**, **312** may increase the predicted and immediate torque requests in a nonlinear manner. The immediate torque limit module **312** may initially increase the immediate torque request at a first rate and then increase the immediate torque request at a second rate that is less than the first rate. The immediate torque request may be increase quickly at first to ensure that the driver does not feel a hesitation or lag in the throttle response. However, the immediate torque request may be increase slowly as the immediate torque request approaches the driver torque request to prevent driveline bump.

The immediate torque limit module **312** may set the immediate torque request equal to the driver torque request minus the torque reserve. To ensure that the immediate torque request is increased by a predetermined torque increment (e.g., 0.5 Nm), the immediate torque limit module **312** may determine the immediate torque request using the following relationship:

$$(T_{im})_{prs}=\text{maximum}(T_{drv}-T_{rsv},(T_{im})_{prv}+\Delta T) \quad (3)$$

where $(T_{im})_{prs}$ is a present immediate torque request, T_{drv} is the driver torque request, and T_{rsv} is the torque reserve, $(T_{im})_{prv}$ is a previous immediate torque request, and ΔT is the predetermined torque increment.

The immediate torque limit module **312** may increase the immediate torque request by decreasing the torque reserve. The immediate torque limit module **312** may exponentially decrease the rate at which the immediate torque request is increased by exponentially decreasing the rate at which the torque reserve is decreased. When the disabled mode is first entered, the torque reserve may be set to the driver torque request minus the present immediate torque request. Subsequently, the torque reserve may be decreased by determining the torque reserve using the following equation:

$$(T_{rsv})_{prs}=(T_{rsv})_{prv}-((T_{rsv})_{prv}*K) \quad (4)$$

where $(T_{rsv})_{prs}$ is a present torque reserve, $(T_{rsv})_{prs}$ is a previous torque reserve, and K is a predetermined rate (e.g., between 0 and 1). To ensure that the torque reserve is decreased to zero, the torque reserve may be decreased by a predetermined amount (e.g., 0.25 Nm) when the immediate torque request is within a predetermined range (e.g., 4 Nm) of the driver torque request.

The predicted torque limit module **310** may initially increase the predicted torque request at a first rate and then increase the immediate torque request at a second rate that is greater than the first rate. When the disabled mode is first entered, the predicted torque request may be much greater than the immediate torque request due to torque limiting. Thus, the predicted torque request may be increased slowly at first since the predicted torque request may have little to no effect on the actual torque output of the engine **102**. However, as the immediate torque request approaches the driver torque request, the predicted torque request may be increased quickly to ensure that the predicted torque request does not interfere with the immediate torque request.

The predicted torque limit module **310** may exponentially increase the rate at which the predicted torque request is increased by determining the predicted torque request using the following equation:

$$(T_{prd})_{prs}=(T_{prd})_{prv}+\Delta T \quad (5)$$

where $(T_{prd})_{prs}$ is a present predicted torque request, $(T_{prd})_{prv}$ is a previous predicted torque request, and ΔT is a torque increment.

The predicted torque limit module **310** may exponentially increase the torque increment by determining the torque increment using the following relationship:

$$(\Delta T)_{prs}=(\Delta T)_{prv}+(\Delta T)_{inc} \quad (6)$$

where $(\Delta T)_{prs}$ is a present torque increment, $(\Delta T)_{prv}$ is a previous torque increment, and $(\Delta T)_{inc}$ is a torque increment increase. The torque increment increase may be determined through calibration and may be fixed or vary as the predicted torque request is increased.

In some cases, driveline bump may still occur as the predicted and immediate torque requests are increased in the disabled mode. Thus, the torque limit modules **310**, **312** may limit the predicted and immediate torque requests for a second time to prevent driveline bump and engine speed flare. When the torque limit modules **310**, **312** limit the predicted and immediate torque requests for a second time, the operating mode of the ECM **114** may be referred to as a retriggered state of the activated mode.

The torque limit modules **310**, **312** may limit the predicted and immediate torque requests for a second time when one or more conditions are satisfied. A first condition may be satisfied when the slip is greater than a slip threshold (e.g., 50 rpm). A second condition may be satisfied when the immediate torque is greater than or equal to a predetermined percentage (e.g., 50 percent) of the driver torque request. A third condition may be satisfied when the immediate torque request is increased in the disabled mode. A fourth condition may be satisfied when the ECM **114** has not yet entered the retriggered state of the activated mode during a present tip-in. A fifth condition may be satisfied when the transmission is either a manual transmission or an automatic transmission with a torque converter clutch in a controlled slip or locked.

When operating in the retriggered state of the activated mode, the torque limits modules **310**, **312** may decrease the predicted and immediate torque requests and then increase the predicted and immediate torque requests in a manner that prevents driveline bump. The predicted torque limit module **310** may limit the predicted torque request in the same way that the predicted torque limit module **310** limits the predicted torque request when the activated mode is first entered. The immediate torque limit module **312** may limit the immediate torque request based on the minimum torque similar to when the activated mode is first entered. However, the immediate torque limit module **312** may limit the immediate torque request based on the minimum torque in a different way when the retriggered state of the activated mode is entered.

When the retriggered state of the activated mode is entered, the immediate torque limit module **312** may decrease the immediate torque request to a torque level that is greater than the minimum torque. The relationship between the torque level and the minimum torque may be predetermined through calibration to ensure that the immediate torque request increases as the minimum torque increases.

Initially, the immediate torque limit module **312** may decrease the immediate torque request by a predetermined percentage (e.g., 50 percent) of a difference between the previous immediate torque request and the minimum torque. The immediate torque limit module **312** may ensure that this initial immediate torque request is greater than an average of the previous immediate torque request and the last immediate torque request determined when the activated mode is first entered. In turn, the immediate torque request is decreased, but not to the degree that it is decreased when the activated mode is first entered to prevent noticeable acceleration delay.

For the remainder of operation in the retriggered state of the activated mode, the immediate torque limit module **312** may determine the immediate torque request based on the initial immediate torque request using the following equation:

$$(T_{im})_{prs}=(T_{im})_{int}-\%*((T_{im})_{int}-T_{min}) \quad (7)$$

where $(T_{im})_{prs}$ is the present immediate torque request, $(T_{im})_{int}$ is the initial immediate torque request, % is the predetermined percentage, and T_{min} is the minimum torque. Determining the immediate torque request using equation (7) ensures that the immediate torque request increases as the minimum torque increases. Additionally, when operating in the retriggered state of the activated mode, the immediate torque limit module **312** may ensure that the immediate torque request does not decrease.

The ECM **114** may operate in the retriggered state of the activated mode for a predetermined period (e.g., 50 to 60 ms). When the predetermined period expires, the disabled mode may be entered for a second time and the torque limit modules **310**, **312** may increase the predicted and immediate torque requests based on the driver torque request. The torque limit modules **310**, **312** may increase the predicted and immediate torque requests in the same way that the torque limit modules **310**, **312** increase the predicted and immediate torque requests when the disabled mode is first entered.

As discussed above with reference to FIG. **2**, one or more (e.g., all) cylinders of the engine **102** may be deactivated and fuel provision to deactivated cylinders may be stopped. Cylinders may be deactivated during a vehicle deceleration to improve fuel economy. When the ECM **114** deactivates cylinders during a vehicle deceleration, the operating mode of the ECM **114** may be referred to as a deceleration fuel cutoff mode.

When the driver tips into the accelerator pedal while the ECM **114** is operating in the enabled, activated, or disabled modes, the immediate torque limit module **312** determines a first torque limit that prevents driveline bump and acceleration delay. The first torque limit may be the immediate torque request that is determined by the immediate torque limit module **312** as discussed above. When the first torque limit is less than the immediate torque request that is output by the immediate torque determination module **304**, the immediate torque limit module **312** may limit the immediate torque request to the first torque limit.

When the driver tips into the accelerator pedal while the ECM **114** is operating in the deceleration fuel cutoff mode, the immediate torque limit module **312** may determine a second torque limit that transitions the engine torque to the driver torque request. The second torque limit may be determined in a way that prevents a sudden increase or jerk in vehicle acceleration as the engine torque is increased from a torque level when fuel provision to deactivated cylinders is stopped to the driver torque request. When the second torque limit is less than the immediate torque request that is output by the immediate torque determination module **304**, the immediate torque limit module **312** may limit the immediate torque request to the second torque limit.

To avoid a conflict between the first torque limit and the second torque limit, the immediate torque limit module **312** may set the immediate torque request to a minimum of the first torque limit and the second torque limit. Limiting the immediate torque request in this manner when the driver tips into the accelerator pedal prevents driveline bump, a delay in vehicle acceleration, and a sudden increase in vehicle acceleration.

Referring now to FIG. **4**, a method of controlling engine torque to prevent driveline bump when a driver tips into an accelerator pedal begins at **402**. At **404**, the method determines whether a tip-in has occurred. A tip-in occurs when the driver depresses the accelerator pedal from a released position. The method may determine that a tip-in has occurred when the percentage of pedal depression is greater than a threshold (e.g., 0 percent) and/or when the period of pedal depression is less than a threshold (e.g., 0.6 seconds). If a tip-in has occurred, the method continues to **406**.

At **406**, the method limits a predicted torque request. The method may adjust slow actuators (e.g., a throttle valve) based on the predicted torque request. The method may limit the predicted torque request by setting the predicted torque request to the estimated torque determined using relationship (1), discussed above with reference to FIG. **2**. The method may limit the predicted torque request for a predetermined period and then increase the predicted torque request to a driver torque request. The driver torque request may be determined based on the position of the accelerator pedal.

At **408**, the method determines whether engine acceleration is greater than a threshold. If the engine acceleration is greater than the threshold, the method continues to **410**. Otherwise, the method returns to **404**. At **410**, the method determines whether slip is within slip thresholds. For an automatic transmission, slip is the difference between the engine speed and a turbine speed. For a manual transmission, slip is the difference between the engine speed and a transmission input shaft speed. The slip is within the slip thresholds when the slip is greater than a first minimum threshold (e.g., 60 rpm) and less than a maximum threshold (e.g., 500 rpm). If the slip is within the slip thresholds, the method continues at **412**. Otherwise, the method returns to **404**.

At **412**, the method determines a first torque limit to prevent driveline bump without causing a delay in vehicle acceleration. At **414**, the method determines a second torque limit to prevent a jerk in vehicle acceleration after fuel provision to one or more cylinders of an engine is stopped. At **416**, the method limits an immediate torque request to a minimum of the first torque limit and the second torque limit. The method may adjust fast actuators (e.g., a fuel injector) based on the immediate torque request.

The first torque limit may include a predicted torque limit and an immediate torque limit. The method may limit the predicted torque request based on the predicted torque limit and limit the immediate torque request based on the immediate torque limit. The method may limit the predicted and immediate torque requests at **416** in the same way that the torque limit modules **310**, **312** of FIG. **3** limit the predicted and immediate torque requests when operating in the activated mode. Thus, the immediate torque limit may be determined based on a minimum torque that prevents the engine from stalling.

At **418**, the method determines whether the immediate torque request has been limited for a period that is greater than a first period (e.g., 100 ms). The first period may be predetermined. When the period torque limiting is greater than the first period, the method continues to **420**. Otherwise, the method returns to **412**.

At **420**, the method increases the predicted and immediate torque requests based on the driver torque request. The method may increase the predicted and immediate torque requests at **420** in the same way that the torque limit modules **310**, **312** increase the predicted and immediate torque requests when operating in the disabled mode. The method may limit the immediate torque request to a minimum of the first torque limit and the second torque limit while increasing the immediate torque request based on the driver torque request.

At **422**, the method determines whether the slip is greater than a second minimum threshold (e.g., 50 rpm). The second minimum threshold may be predetermined. If the slip is greater than the second minimum threshold, the method continues at **424**. Otherwise, the method returns to **404**.

At **424**, the method determines whether the immediate torque request is greater than or equal to a product of a predetermined percentage (e.g., 50 percent) and the driver torque request. If the immediate torque request is greater than or equal to the product, the method continues at **426**. Otherwise, the method returns to **404**.

At **426**, the method determines whether the immediate torque request is increasing. When the immediate torque request is increasing, the method continues to **428**. Otherwise, the method returns to **404**. At **428**, the method determines whether limiting the immediate torque request has been retriggered during a present tip-in. When limiting the immediate torque request has not yet been retriggered, the method continues to **430**. Otherwise, the method returns to **404**.

At **430**, the method determines whether a vehicle is equipped with an automatic transmission or a manual transmission. If the vehicle is equipped with an automatic transmission, the method continues to **432**. Otherwise, the method continues at **434**. At **432**, the method determines whether a torque converter clutch that couples the automatic transmission to the engine is in a controlled slip or locked. If the torque converter clutch is in a controlled slip or locked, the method continues to **434**. Otherwise, the method returns to **404**.

At **434**, the method determines a first torque limit to prevent driveline bump without causing a delay in vehicle acceleration. At **436**, the method determines a second torque limit to prevent a jerk in vehicle acceleration after fuel provision to one or more cylinders of an engine is stopped. At **438**, the method limits the immediate torque request to a minimum of the first torque limit and the second torque limit.

The first torque limit may include a predicted torque limit and an immediate torque limit. The method may limit the predicted torque request based on the predicted torque limit and limit the immediate torque request based on the immediate torque limit. The method may limit the predicted and immediate torque requests at **438** in the same way that the torque limit modules **310**, **312** of FIG. **3** limit the predicted and immediate torque requests when operating in the retriggered state of the activated mode.

At **440**, the method determines whether the immediate torque request has been limited for a period that is greater than a first period (e.g., 50 to 60 ms). The first period may be predetermined. When the period torque limiting is greater than the first period, the method continues to **442**. Otherwise, the method returns to **434**.

At **442**, the method increases the predicted and immediate torque requests based on the driver torque request. The method may increase the predicted and immediate torque requests at **442** in the same way that the torque limit modules **310**, **312** increase the predicted and immediate torque requests when operating in the disabled mode. The method may limit the immediate torque request to a minimum of the first torque limit and the second torque limit while increasing the immediate torque request based on the driver torque request. The method returns to **404** when the predicted and immediate torque requests have been increased to target torque levels.

Referring now to FIG. **5**, a predicted torque limit **502** and an immediate torque limit **504** are illustrated. The predicted torque limit **502** and the immediate torque limit **504** limit a predicted torque request and an immediate torque request, respectively. The predicted and immediate torque limits **502**, **504** are plotted with respect to an x-axis **506** that represents time in seconds and a y-axis **508** that represents torque in Nm.

At a time **510**, the predicted torque limit **502** is decreased to limit the predicted torque request in response to a tip-in. At a time **512**, the immediate torque limit **504** is decreased to limit the immediate torque request in response to a difference between engine speed and a turbine speed or a transmission input shaft speed. The period between the times **510**, **512** corresponds to operation in the enabled mode.

At a time **514**, the predicted and immediate torque limits **502**, **504** are increased based on a driver torque request. The period between the times **512**, **514** corresponds to operation in the activated mode. At a time **516**, the predicted torque limit **502** reaches its target and therefore is increased to stop limiting the predicted torque request. At a time **518**, the immediate torque limit **504** reaches its target and therefore is increased to stop limiting the immediate torque request.

The period between the times **514**, **518** corresponds to operation in the disabled mode. Thus, the predicted and immediate torque limits **502**, **504** may be adjusted in the nonlinear manner during this period. The immediate torque limit **504** may be increased quickly at first to prevent acceleration delay and then slowly to prevent driveline bump. The predicted torque limit **502** may be increased slowly at first and then quickly as the predicted torque limit **502** approaches its target to avoid interfering with the immediate torque limit **504**.

The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. For purposes of clarity, the same reference numbers will be used in the drawings to identify similar elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A or B or C), using a non-exclusive logical OR. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure.

As used herein, the term module may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC); an electronic circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor (shared, dedicated, or group) that executes code; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip. The term module may include memory (shared, dedicated, or group) that stores code executed by the processor.

The term code, as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, and/or objects. The term shared, as used above, means that some or all code from multiple modules may be executed using a single (shared) processor. In addition, some or all code from multiple modules may be stored by a single (shared) memory. The term group, as used above, means that some or all code from a single module may be executed using a group of processors. In addition, some or all code from a single module may be stored using a group of memories.

The apparatuses and methods described herein may be implemented by one or more computer programs executed by one or more processors. The computer programs include processor-executable instructions that are stored on a non-transitory tangible computer readable medium. The computer programs may also include stored data. Non-limiting examples of the non-transitory tangible computer readable medium are nonvolatile memory, magnetic storage, and optical storage.

What is claimed is:

1. A system comprising:

a torque determination module that determines a first torque that prevents an engine from stalling; and

a torque limit module that controls engine torque based on a sum of the first torque and a torque offset when a driver actuates an accelerator pedal from a first position in which the accelerator pedal is not depressed to a second position in which the accelerator pedal is depressed.

2. The system of claim **1** wherein the torque limit module limits the engine torque for a first period when a first difference between engine speed and one of turbine speed and transmission input shaft speed is greater than a first threshold.

3. The system of claim **2** wherein, during the first period, the torque limit module limits the engine torque based on a sum of the first torque and a torque offset.

4. The system of claim **2** wherein the torque limit module adjusts the engine torque based on a driver torque request when the first period ends.

5. The system of claim **4** wherein the torque limit module limits the engine torque for a second period when the first difference is greater than a second threshold after the first period ends.

6. The system of claim **5** wherein, during the first period and the second period, the torque limit module limits the engine torque based on a minimum of a first torque limit that prevents driveline bump and a second torque limit that transitions the engine torque to the driver torque request after fuel provision to a cylinder of the engine is stopped.

7. The system of claim **5** wherein, during the second period, the torque limit module limits the engine torque based on a second difference between a previous torque request and the first torque.

8. A system comprising:

a torque determination module that determines a first torque that prevents an engine from stalling; and

a torque limit module that:

limits engine torque based on the first torque when a driver actuates an accelerator pedal from a first position in which the accelerator pedal is not depressed to a second position in which the accelerator pedal is depressed;

limits the engine torque for a first period when a first difference between engine speed and one of turbine speed and transmission input shaft speed is greater than a first threshold;

adjusts the engine torque based on a driver torque request when the first period ends;

limits the engine torque for a second period when the first difference is greater than a second threshold after the first period ends;

limits the engine torque during the second period based on a second difference between a previous torque request and the first torque; and

limits the engine torque based on a third difference between the previous torque request and a product of a predetermined percentage and the second difference during the second period.

9. The system of claim 8 wherein the torque limit module adjusts the engine torque based on the driver torque request when the second period ends.

10. The system of claim 9 wherein the torque limit module increases the engine torque in a nonlinear manner when the first period ends and when the second period ends.

11. A method comprising:

determining a first torque that prevents an engine from stalling; and

controlling engine torque based on a sum of the first torque and a torque offset when a driver actuates an accelerator pedal from a first position in which the accelerator pedal is not depressed to a second position in which the accelerator pedal is depressed.

12. The method of claim 11 further comprising limiting the engine torque for a first period when a first difference between engine speed and one of turbine speed and transmission input shaft speed is greater than a first threshold.

13. The method of claim 12 further comprising limiting the engine torque during the first period based on a sum of the first torque and a torque offset.

14. The method of claim 12 further comprising adjusting the engine torque based on a driver torque request when the first period ends.

15. The method of claim 14 further comprising limiting the engine torque for a second period when the first difference is greater than a second threshold after the first period ends.

16. The method of claim 15 further comprising limiting the engine torque during the first period and the second period based on a minimum of a first torque limit that prevents driveline bump and a second torque limit that transitions the engine torque to the driver torque request after fuel provision to a cylinder of the engine is stopped.

17. The method of claim 15 further comprising limiting the engine torque during the second period based on a second difference between a previous torque request and the first torque.

18. A method comprising:

determining a first torque that prevents an engine from stalling;

limiting engine torque based on the first torque when a driver actuates an accelerator pedal from a first position in which the accelerator pedal is not depressed to a second position in which the accelerator pedal is depressed;

limiting the engine torque for a first period when a first difference between engine speed and one of turbine speed and transmission input shaft speed is greater than a first threshold;

adjusting the engine torque based on a driver torque request when the first period ends;

limiting the engine torque for a second period when the first difference is greater than a second threshold after the first period ends;

limiting the engine torque during the second period based on a second difference between a previous torque request and the first torque; and

limiting the engine torque based on a third difference between the previous torque request and a product of a predetermined percentage and the second difference during the second period.

19. The method of claim 18 further comprising adjusting the engine torque based on the driver torque request when the second period ends.

20. The method of claim 19 further comprising increasing the engine torque in a nonlinear manner when the first period ends and when the second period ends.

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